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Hydropower expansion and analysis of the use of strategic and integrated environmental assessment tools in Brazil

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ABSTRACT

In Brazil, over the next two decades, an additional 31.7 GW will be added to the hydropower sector in the northern region, to keep pace with the country's growing economy. Due to the socio-environmental vulnerability of this region, there is international concern about its conservation. Since 2007, the hydroelectric potential inventory has employed Integrated Environmental Assessments (IEA), taking into consideration an analysis of the cumulative and synergistic impacts of all the hydropower plants in the river basin. Also available is the Strategic Environmental Assessment (SEA), a tool that has been used by the National Water Agency in its Strategic Water Resources Plan, which aims to support decision making at the political, planning, and program levels in the river basin, employing sustainable development scenarios. Both tools have been recently used in Brazil, and this paper aims to analyze their differences and their main contributions to the decision-making process in the Brazilian power sector. Therefore, we analyzed 3 studies on the implementation of new hydropower plants in the Tocantins–Araguaia River Basins: the Strategic Water Resources Plan for Tocantins and Araguaia River Basins—PERH-TA (using the SEA methodology), the IEA of the Tocantins River Basin and the IEA of the Araguaia River Basin, analyzing their methodologies, scenarios, results and recommendations. We found that the SEA, in contrast to the IEA, provides a broader and more independent vision about the social and environmental impacts. After the conclusion of the integrated and strategic studies, we verified that some recommendations are not being followed in the HPP planning process, since some dams had problems with environmental licenses, as mentioned in the studies. Therefore, we conclude that methodological adjustments, as well as political and institutional enhancements in these processes could make the tools more useful.

Contents

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1. Introduction

Population and economic growth in developing countries, is demanding high levels of energy in order to meet increasing modern life conveniences [1]. Electricity production is rising significantly in order to provide higher economic welfare, using hydropower as an advantageous alternative for clean energy at a stable price [2]. However, the pressure over the government for water management is becoming more intense since half of the rivers all over the world are with an unprecedented rate of dam construction [3].

In many countries the Environment Strategic and Integrated tools are being adopted at the government planning level, aiming to help in the decision-making process and to improve the Environment Impact Assessment (EIA) process. SEA's use has been encouraged by Multilateral Development Agencies such as the Inter-American Development Bank (IADB) and the World Bank for investment's approval [4,5]. In contrast, the IEA (as a Cumulative Impact Assessment), is required to study the environmental fragilities and assess the consequences of hydropower plants' (HPP) sets on river basins, *e.g.* [6].

The Strategic Environment Assessment (SEA) started to be used with the USA National Environmental Policy Act—NEPA in 1969 [7], but it has acquired international recognition in the conventions of the European Union (SEA Directive, 2001) and in the Kiev Protocol, 2003, of the United Nations Economic Commission for Europe (UNECE) [8], and the Integrated Environment Assessment (IEA) emerged in 1974, through the United Nations Educational, Scientific and Cultural Organization (UNESCO) International Hydrological Program (IHP) [9] and it is most used at the level of river basins.

SEA is also applied for river basin studies concerning the impact assessment of large hydropower plants developments, as in the Mekong River Basin, in South Asia [10] and the Madeira River Complex, in the Amazon River Basin, in Brazil [4]. It has also been suggested for many other countries like Russia and Canada [11,12], since they are big hydroelectricity producers. Recently, an assessment tool for the SEA and IEA effectiveness evaluation has been suggested by some international institutions [3–10,83,84][1].

Brazil has the third largest technically feasible hydropower potential in the world with 1488 TWh/year, after China (1920 TWh/year) and Russia (1670 TWh/year) [15]. The hydroelectric production accounts for around 70.0% of the Brazilian electricity supply matrix; its currently installed capacity is 91,348,000 MW [17].

Although it is not mandatory, the Brazilian government recommends[2] implementing the SEA for planning processes [8–17]. Out of 38 SEAs already developed in Brazil [8–17,2–23], 7 are about water resources management [6–17].

The IEAs in Brazil is linked to the 2007 Hydropower Inventory Studies of River Basin Manual, under the responsibility of Energy Research Company (EPE) [22]. This Inventory demonstrates, through the marginal costs of electricity expansion, the direction that the Brazilian Power Sector's long-term plans (the National Energy Plan) should take [25] and the IEA aims to contribute to the selection of alternatives that maximize generation and reduce and neutralize adverse environmental impacts after analyzing all the HPP projects in the river basin [6–27].

So far, 14 IEAs have been conducted for Brazilians river basins, mainly in the Amazon Region [27]. Amazon and Tocantins river Basins will be responsible for nearly 80% of new hydropower plants in the country [16], in order to meet the projected increase of electricity consumption by 4.3% per year [29]. However, there are increasing concerns regarding the environmental and social fragilities of these regions, because of indigenous and riparian communities and natural protected areas.

Given these facts, the Energy Sector plays an important role in these environmental assessments on river basins where the planned hydropower plants will be installed. "Energy planning and environmental licensing must be compatible with sustainable development and a strategic vision of the territory in the manner specified in the Strategic Environmental Assessment (SEA) and the Integrated Environmental Assessment (IEA)" [9].

Thus, this paper aims to show how SEA and IEA are being applied in the Brazilian River Basins considering its main contribution for the performance of the electric sector on environmental issues. The case studies analyzed in this paper are (1) the Strategic Plan for Water Resources (PERH-TA) for the Tocantins and Araguaia Hydrographic Region, adopting the SEA methodology, (2) the Environmental Integrated Assessment developed in Araguaia and (3) the Environmental Integrated Assessment developed in the Tocantins River Basins. We will discuss the main results of the assessments, analyzing their contributions to sustainable development in these Brazilian river basins in relation to the hydropower plants installation. Fig. 1 presents Tocantins and Araguaia Hydrographic Region Map.

2. HPP expansion in Amazonia hydrographic region

The hydropower potential of the Amazon region raises important environmental concerns. The great biodiversity of the Amazon region, with large areas of preservation, forests, and prevalent indigenous reserves, leads to potential conflict between land use, environment preservation and water resources (National Water Agency *apud* Castro) [35]. The region is home to an estimated 20% of all species on the planet, including more than fish 3000 species, in addition to many others that have not yet been identified [36].

Neighboring the Amazon biome, the Cerrado (Brazilian Savannah) has also a great importance. It is one of the world's 25 *hotspots* (critical areas for conservation in the world), providing fundamental environmental services for soil maintenance, climate regulation, and water supply (*e.g.*, plants with deep roots) [37], in addition to being a region that is home to diverse and unique fauna and flora, according to the National Environmental Agency—IBAMA *apud* Lopes) [38].

The Hibam project states that the *El Niño Southern Oscillation* (*ENSO*) affects the hydrology and geochemistry of the Amazon River Basin, "which causes a significant decrease in rainfall". In addition, it is important to note that, the phenomenon of some hydraulic blockages along the main course of the Amazon River is not yet considered as "the impact of this climatic variability on erosion and on the flow of objects transported throughout the Amazon River basin remains to be discovered" [39].

Table 1 presents some characteristics of the Tocantins and Araguaia River Basins.

According to Brazil's Ten-Year Energy Plan 2021 [29], the current situation of the hydropower plants in these regions is shown in Table 2

Both regions shown in Table 2 have an installed capacity of 18.4 GW (5.3 and 13.1 GW respectively) which is expected to increase this by 24.8 GW.

It is worth noting that only 9 of the 41 planned, under construction or existing dams are of water accumulation reservoir dams that aim to maximize electricity generated [29], allowing for greater energy security of the system during the dry season. However, individually, they can cause much greater environmental impacts than run-of-river plants because of a smaller flooding area. Since there are few hilly

[1] Rapid Basin-wide Hydropower Sustainability Assessment Tool aiming to contribute for a greater efficiency of the SEA and IEA tools [9].

[2] Court of Audit Resolution n. 464/2004 [30,31] and Law project 261/2011 [32].

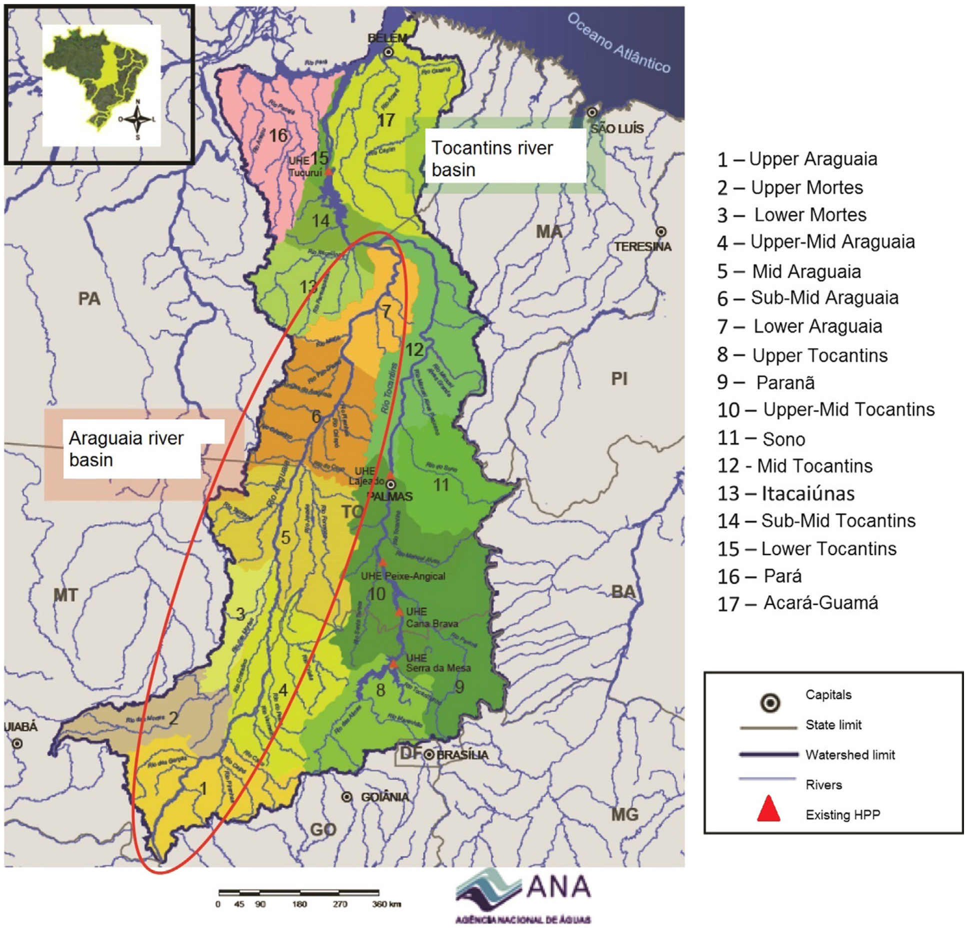

Fig. 1. Tocantins and Araguaia hydrographic region map.
Source: [9–40,42].

Table 1
Main characteristics of the Tocantins and Araguaia River Basins.
Source: Adapted from [17,41,4–43(a)].

Main characteristics of the Tocantins and Araguaia River Basins
With 813,674.1 km² and 5,346,120 inhabitants, approximately 50% of this area's population lived below the poverty line in 2000, according to IBGE *apud* ANA (2009). The total power generation in the region is 23,825 MW, with 84% falling within the Tocantins watershed and 16% within the Araguaia watershed (ANA 2009).
The Tocantins river has 1400 km and the sub-middle and lower (Lower) Tocantins and Acará-Guamá sub-regions are 100% urbanized, with low basic sanitation infrastructure(a); Its most environmental fragile region is the Sono river, that has the last remaining large Savannah preserved in the tourist region of Jalapão (presence of the loon duck, waterfalls, and sand dunes). Currently there is 7 HPP in the river basin, and they take up about 40% of the length of the river and 68% of the hydroelectric potential has already explored (installed power) along the 992 km of the Tocantins River.
The Araguaia river length is about 2600 km and its Economic activities are based basically on tourism, mining, and agriculture (Upper and middle Araguaia region). The most special area of this river basin is the Bananal Island, whose region is home to 14 indigenous communities, where touristic tours, sport fishing and leisure activities on beaches river are developed and where aquatic and terrestrial ecosystems are in good condition with a great biological diversity. In this River Basin there are six Small Hydropower Plants (SHP)

Table 2
Current situation of HPP implementation in Amazon and in Tocantins and Araguaia River Basins.
Source: [46]

Hydrographic region	In operation	Under construction	Planned
Amazon river	7 HPP (5.3 GW)	3	12
Tocantins and Araguaia rivers	11 (13.1 GW) and 10 SHP[a]	0	11
Total	28	3	23

[a] SHP—Small Hydropower Plant—With characteristics of installed potency between 1 and 30 MW and a reservoir area of up to 3 km², "the SHPs are ideally suited to meeting the energy demands of small urban enters and rural areas" [46].

reliefs in the Amazon region and large flooding areas are needed per MW, then, the most environmentally viable dam is the run-of river type, in order to reduce environmental and social costs [47].

The diagram below (Fig. 2) shows the existing dams in these watersheds (in 2006) and those planned for 2015 and 2025, according to PERH-TA.

Some of the main impacts caused by dams on the Amazon rivers have been stated by many authors, some of them being [52]

– High levels of Greenhouse Gases Emissions due to flooded forested areas, as in the Balbina and Turcuruí Dams [9–48] for example, in addition to the loss of large amounts of commercial timber (about 40–60 m³/ha);

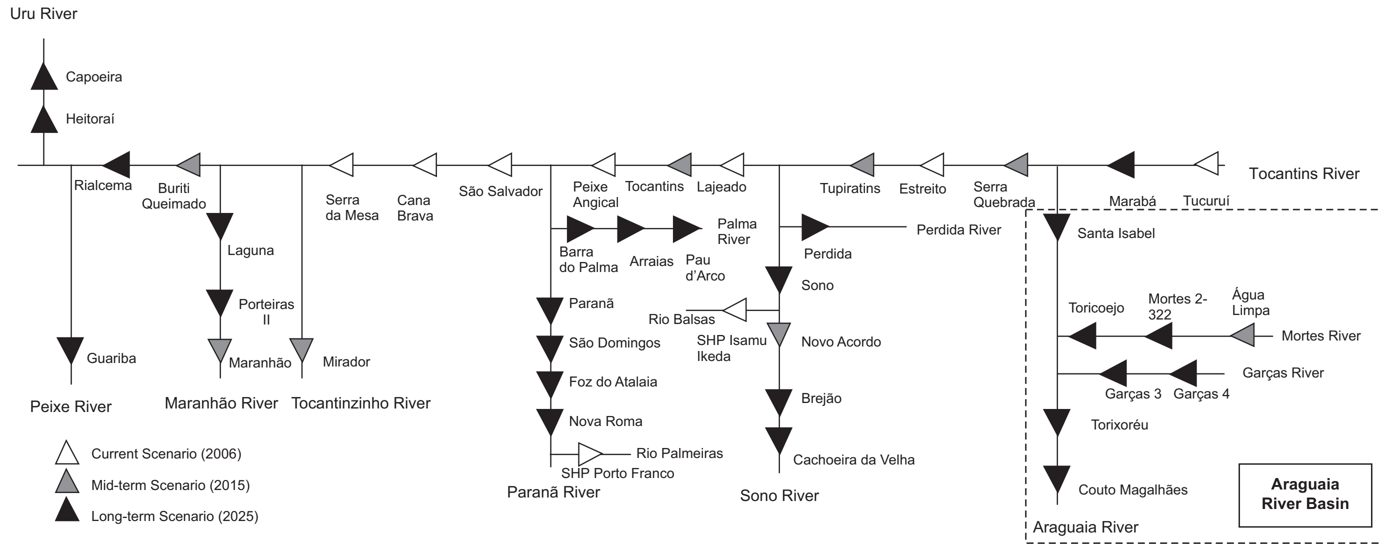

Fig. 2. Schematic arrangement of the hydropower plants in the Tocantins and Araguaia River Basins, foreseen for 2025 (according to PERH-TA and Tocantins IEA). *Source*: Adapted from EPE [43].

– Intervention on preserved areas and indigenous land (as Belo Monte dam) that does not comply with the Federal Constitution of 1988, Chapter VIII, art. 231 [53], and with the Convention 169 of the International Labor Organization—ILO (art. 6) about indigenous rights [55,56]. The National Energy Plan 2030 establishes that by 2015, 6.9% of planned dams will cause interference in indigenous lands and conservation units, and by 2030, 28.3% of planned dams will be environmentally complex or will be located in areas that we have limited environmental knowledge [56].
– Population displacement (Brazil has more than 200,000 families, who were displaced to give place to reservoirs [6–57];
– Losses of minerals, archeological places and natural conservation areas;
– Changes in water quality (*e.g.* massive growth of aquatic weeds);
– Interference in fishes displacement and reproduction and others aquatic biodiversity reduction in its longitudinal connectivity [59] as the reproductive cycle of turtles on the river beaches and reduced food supply for alligators, when changing the river support system of the floodplains or the Igapós (natural flooded forest);
– Losses in electricity transmission [60] far away from the electric load center of the country. It is estimated that there will be around 20% of losses [61].

The ecological costs of the Amazon River's exploitation are unknown since they have not been properly studied, and “in the long term, social and economic costs have not been adequately correlated to the benefits; and solutions will be costly, time-consuming, and politically difficult” [35,52].

Based on these ecological and social aspects of the Amazon and Cerrado biomes, “The question is to assess, in broad and critical terms, what it would mean to have another hydropower plant in the region”, i.e., their cumulative and synergistic impacts on the basin must be carefully assessed [62].

Despite the negative impacts and disregarding the feasibility of some of the dams [63], the cost of electricity could rise some 40% if the thermal power plants start to operate to supply the energy demand and, consequently, cause an increase in CO_2 emissions [3–64]. This situation is highly undesirable to the Brazilian government, who is committed to maintaining emissions levels in the electricity sector in 2020 equal to those in 2005, according to the 15th Conference of the Parties to the UNFCCC [28,45]. On the other hand, the environmental and social impacts of the renewable energy must not be “overlooked in providing low-carbon energy” [66]. Thus, “the decision-making process becomes extremely complex” considering all the technical, economic criteria along with the environmental ones [35,67].

3. Environmental management tools and the hydropower expansion planning in Brazil

The legislative developments in the power and environmental management sectors (such as the creation of ANEEL, Law no. 9427 [68], the implementation of the National Water Resources Plan and of the National Water Resources Management System, Law no. 9433 [69], and the creation of the National Water Agency, Law no. 9984 [70], among others) led to the revision of the Hydropower Inventory Studies Manual. The Hydropower Inventory aims to select a best alternative based on a cost-benefit analysis, taking in to account energy and economic studies of hydropower undertakings, and preliminary environmental impacts assessments in the Integrated Environment Assessment (IEA) of the river basin [71].

Based on the Inventory's results, the Brazilian National Energy Plan (*PNE 2030*), the master plan of the energy sector, strives to predict the state of the sector for the next 20 years. The agenda for the electric energy sector is reviewed by the Ten-Year Plan (PDE), which considers changes in the economic and environmental viability of the endeavors.

To build and operate a new HPP the electric sector has to accomplish the following technical and socio-environmental proceedings:

– Undertake technical and economic feasibility studies of the hydropower plants [1–72];
– Develop the Environment Licensing process (CONAMA Resolution n. 01/86) [74], starting with the Environmental Impact Assessment (EIA) to acquire the Previous Permit;
– Prepare the Basic Environmental Plan to be implemented by the energy concessionaire after approval of the Previous Permit by the environmental agency [75];
– Acquire Installation Permit, after executive project approval
– Acquire Operating License, acquired after the project construction's approval;
– Pay the financial compensation or royalties corresponding to 6.75% of the value of the sales of the produced energy

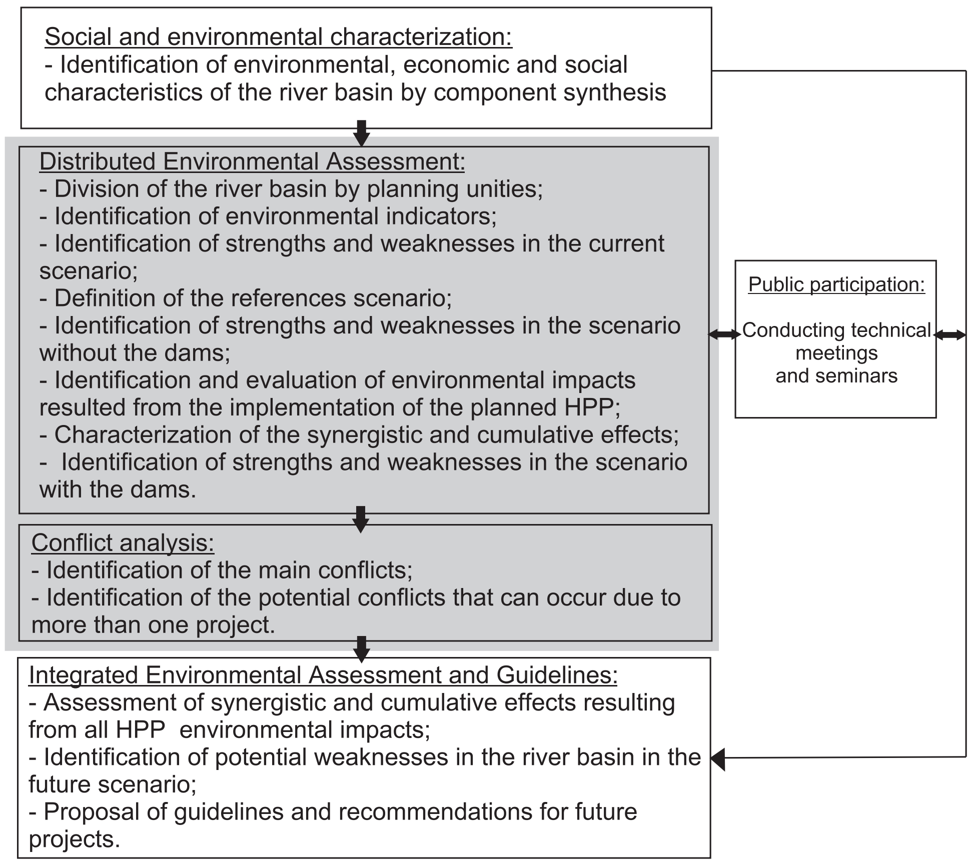

Fig. 3. IEA's methodological procedures applied for the hydropower sector.
Source: [27].

(MWh)[3] by energy concessionaire, when it starts operating the power plant [76]. It represents an important resource for many municipalities with HPP reservoirs and also contributes to the Programs of the National Water Policy *etc*. [77].

3.1. Integrated environmental assessment

The Inventory Studies Manual provides the methodology to be followed for carrying out the IEA study, which requires the creation of several "sustainability indicators" [78] upon which the guidelines and recommendations are based.

The IEA's objectives and strategies are defined as follows [9]:

- Analyze the cumulative effect that come from increased incidence of localized impacts generated by other similar projects in the same river basin, intensifying them and the synergistic effect, that go beyond the physical limits of the river basin and interact with impacts from other projects, producing an effect distinct from those that originated it [39], of HPP sets on natural resources and human populations;
- Assess the current and potential uses of water resources for current and future planning, taking into account the need to balance energy generation with biodiversity conservation and maintaining gene flow of aquatic species;
- Consider social diversity and economic development of the basin, in light of the national legislation and the international commitments undertaken by the Federal Government.

Compared to the SEA, the IEA considers issues more directly related to the interference caused by the reservoirs, such as damages to fish populations, increased vulnerability of aquifers, pressure on health facilities, interference with riparians and indigenous populations and risks for the preservation of archeological sites. IEA as well as SEA, aims to provide input for the decision-making process.

The methodological content is presented in Fig. 3

Initially the IEA carries out a socio-environmental description of the river basin according to the criteria and indicators associated to the hydropower reservoirs (known as "Components-synthesis") such as Aquatic (Water quality, Conflicts in water uses, Aquatic environment) and Terrestrial Ecosystems (Soil erosion, Terrestrial ecosystems), Livelihoods (Life conditions, Land use conflicts, Change or disarticulation of sensitive communities), Territorial Organization (Populations pressure caused by the attracted population because of the new HPP on the region) and Economic (Change in Economic activities and Positive economic effects of the reservoirs) [2–43].

Then, a Distributed Environmental Evaluation (*Avaliação Ambiental Distribuída*—ADA), divides the basin in sub-regions or planning units that possess similar environmental and/or socio-economic characteristics. Sensitivity (environmental reaction and changing of the quality of their state when affected by human action) [40] and Fragilty (sum of the area sensitivity added to the

[3] The 6.75% of the sale of produced energy is distributed as follows: 0.75% goes to the MMA, and 45% of the remaining 6% are distributed to the municipalities (proportionally to the area assigned to the reservoir), another 45% go to the state, and 10% to federal institutions (3% to the Ministry of the Environment, 3% to the Ministry of Mines and Energy, and 4% to the Ministry of Science and Technology), (Law 7990/1989, altered by Law 8001/1990) [66].

impacts caused by human activities) [44] indicators are identified (delimitating environmentally and socially fragile areas and characterizing the environmental effects of the HPP' set for each sub-region).

The Hydropower Inventory Studies Manual [25] suggests that the weight (which can vary from 0 to 1 for classification of impacts) that reflects the relative importance of the positive socio-environmental impacts should not be greater than 0.25, in order to not overestimate the positive impacts compared to the negatives ones.

A further analysis generally using a decision matrix based on many criteria of the combined effects of the socio-environmental variables and the analyzed indicators [68] aims to identify the local conflicts and those that could occur due to an additional project in the same sub-basin, verifying if there are synergistic effects that can extrapolate the sub-regions [44].

Based on this process, alternative development scenarios for the river basin are created and prediction maps are drawn, indicating where the main cumulative and synergistic impacts will occur, or where the sensitive areas of the river basin are, in each of the scenarios. After analyzing the positive and negative impacts in wide-river basin, all of the cumulative and synergistic effects are identified and the hydropower project is selected based on a hierarchy of alternatives according to a "preference index"[4] that takes into account the better energy cost-benefit index and the negative socio-environmental impact index. It also identifies the areas of least socio-environmental fragility (which does not necessarily correspond to the areas with environmental or project feasibility) and advises about cost increases, and the complexity of analyzing and granting licenses [26].

3.2. SEA in the strategic water resources plan for river Basins

SEA aids to integrate environmental and sustainability issues in the decision-making process, "evaluating strategic development options" [79] and it is usually applied at a higher level of the decision-making process [80,81], or in every "substantial developing policy" or strategic land use or spatial planning [80–82]. Thereby, SEA tries to "overcome projects reductionism" [83].

The principles of SEA are to identify the best option for strategic action, minimize negative impacts, optimize positive impacts, and compensate for the loss of valuable features and benefits and ensure that strategic actions do not exceed limits beyond the damage that may occur from such impacts [81].

SEA's effectiveness depends on the extent to which the methodology considers the context of the study, its processes (public and stakeholder's participation, mitigation actions, implementation of strategic actions and monitoring results) and results [81]. The responsibilities must be well defined, as well as the quality of the information and the timing of its development [4–75].

Fig. 4 shows the SEA methodology, on the side of the Strategic Water Resources Plan (*e.g.* for the Tocantins–Araguaia Region, with the PERH-TA).

Beyond the classic environmental licensing process [74], and because of the lack of organized River Basins Committees (only in five of the 12 Hydrographic Regions of the country have one [85], the National Water Agency is carrying out the Strategic Water Plans for river basins that do not have installed committees (this is the case, for instance, in the Right Banks of Amazon River (PERH-MDA) [86] and for Tocantins and Araguaia River Basins (PERH-TA)) [41].

A good example of an integrated development of shared basins to be followed is the River Basin Development Management of Tennessee Valley Authority, in USA, that considers the multiple water uses (navigation, electricity, employment, countering soil erosion among others), and environmental management [87].

4. Application of SEA and IEA tools in the Tocantins and Araguaia river basins

The PERH-TA [39] considered some environmental issues such as the potential regulation of river flows, urban population with disposal of solid waste, hydropower generation, financial compensation and management level of the basin.

The PERH-TA methodology defined the context and established the critical factors for the decision, by determining the strong points (potentialities) and weak points (fragilities) intrinsic to the region of study, utilizing a SWOT matrix (Strengths, Weaknesses, Opportunities, and Threats), thereby identifying the strategic issues of the water basin.

It sought to define the strategic sustainability objectives: (I) water availability and quality; (II) multiple, rational, integrated, and sustainable uses of water resources; (III) improvement in the quality of life of the populations in the affected areas; (IV) environmental sustainability to preserve water resources; and (V) promotion of governance and integrated management of water resources. After this, three scenarios were created (Tendency, Plan and Alternative Scenarios), based on a 3.5% GDP in 2007 and 2015 and a 4.5% GDP in 2025. In the last two scenarios, the existence of a good environmental management was considered in order to estimate the results of economic growth depending on the quality of governance in the region.

The Tocantins River Basin IEA [43] impact indicators[5] were analyzed based on their significance, intensity, and magnitude (the results are shown in the maps presented in this study). The impacts indicators were first analyzed separately and the cumulative effects were later analyzed by river basin and by timeline.

However, the weight attributed to "increasing diversification of the economy, improving the quality of life" in the Tocantins IEA was 0.5 (higher than the upper limit defined by the Inventory) [43]. This high grade was justified by the beneficial transformation potential of the region due to the implementation of hydropower plants in Tocantins River Basin. Nevertheless it can create a bias in the study's overall results by overemphasizing the assessment of positive impacts as compared to the negative ones. In order to assess the synergy, the Tocantins IEA made use of a Binary Square Matrix of Impacts, applied per compartments and inter-compartments of the basin, where the magnitude of the impact could be translated into fragility or potentiality of the area.

The environmental indicator analysis results have shown that the general classifications of the median impacts were maintained throughout the period of study, with a general increase after the installation of the hydropower plants in the basin, except for certain regions, the lower course and mouth of the river basin, and the left bank and upstream of the mouth of the Araguaia river regions, where the intensity of the impacts diminished in the medium course [44]. Based on the impact results, three scenarios

[4] Preference Index: [I=Pcb x (ICB/CUR)+ pa X Ian], where Pcb=weight that reflects the relative importance of the "energy cost-benefic index"; ICB=energy cost-benefit index, in R$/MWh; CUR=reference unitary cost, in R$/MWh; Pa=-weight that reflects the relative importance of the objective of "minimizing the negative socio-environmental impact"; and Ian=negative environmental impact index [25].

[5] Examples are: alteration of the dynamic hydraulics and of the water quality, interruption of the migratory fish routes, loss of areas for nature conservation and loss of productive areas, attracting populations, affected populations, socio-cultural interference of indigenous populations, alterations/loss of cultural expressions and compromising of archeological assets.

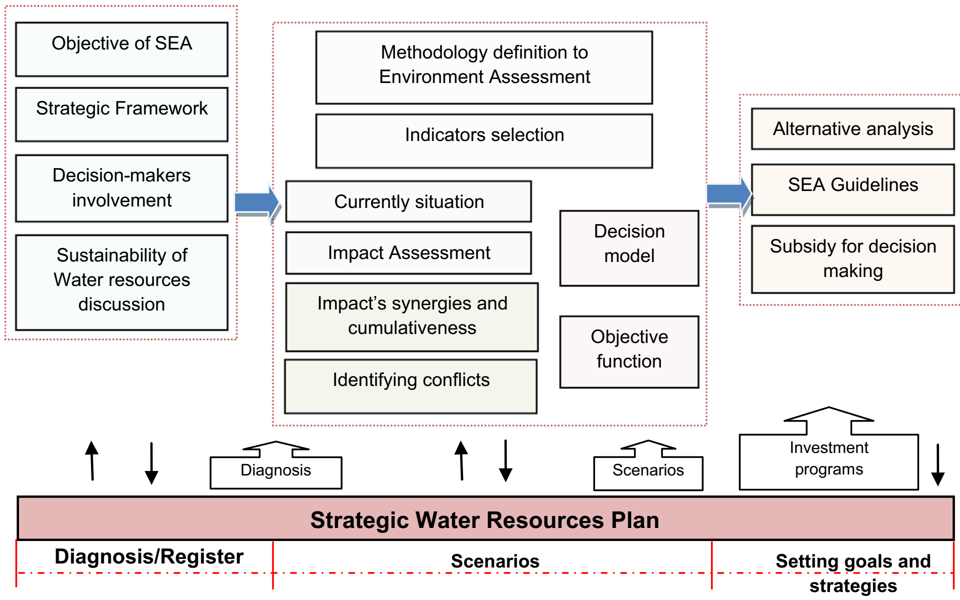

Fig. 4. AAE's methodological procedures applied for the strategic water resources plan.
Source: [84].

were developed (Present—2006, Tendency—2015 and Future—2025).

The IEA Araguaia River Basin defined some impact indicators based on their importance and magnitude according to the reservoir's operating system, residence time, regulating capacity, power, area, flow reduction and dam height. The Relational Flow of Environmental Events (*FREA* in Portuguese) model was applied to identify the events responsible for the most important environmental transformations. The reversibility of impacts was also verified.

Regarding the 70 alternatives of hydropower potential identified by the Hydropower Inventory Study, one was chosen (covering 8 projects located in a basin further south)[6]. According to EPE, this alternative does not interfere in the Bananal Island (region with higher sensitivity in the Araguaia river) or in its fluvial dynamics, "respects PERH-TA recommendations" and presents a better balance between the costs of implementation, the energy benefits and the socio-environmental impacts.

Using the ranking of the cumulative and synergistic impacts, and following closely the guidelines of the inventory manual, only two scenarios were developed, taking into account the sensitivity of the basin subareas (Current Scenario—2007 and Future Scenario—2027).

The scenarios results of the studies are shown in Table 3:

Only PERH-TA and the Tocantins river IEA considered the current, medium and long-term scenarios in the analyses, which allowed a better perception of the changes caused by the cumulative impacts of the HPPs over time, in comparison to the Araguaia IEA, which only considered 2 scenarios.

The results of the PERH-TA underline the risks and mitigation recommendations regarding social and ecological vulnerability, and water use linked to the HPP installation. First, the PERH-TA study emphasizes that in Araguaia River, because of the great number of protected areas, the Mid-Araguaia and the Sono River should have a Water Management Plan before the dam can be built. Regarding river navigation, PERH-TA emphasizes that this river's waterways are not prioritized and suggests that the Araguaia River should be conserved, free of large and medium hydropower plants.

Regarding the Tocantins River Basin, the results recommend developing further studies about navigation and irrigation, improving basic sanitation to reduce the water pollution and creating a relocation program for the population. The study states that the relocation of populations should be consistent "to ensure proper resettlement of the affected population". There will only be an increase in the municipal tax collection in the upper and lower regions of the Tocantins River, as well as the addition of basic sanitation to urban areas, due to the financial compensation [41].

The IEA Tocantins identifies that besides generating direct and indirect jobs in the region, the group of projects can lead to the loss of forested areas and the flooding of up to 21% of existing vegetation (considering the future scenario) affecting the regional ecosystem and some tourist areas such as the Sono River.

"Most of the effects on the ecosystem dynamics of local economies and on the living conditions of the people in these areas, among other changes, are already present and are being internalized" with reference to the existing dams in some areas of the original and continuous ecosystem in the Tocantins River [43].

The main recommendations of the IEA Tocantins are [43]: Rescue of archeological information; Tourism support for the region and the reservoirs; Promotion of environmental education; Support for the enhancement of natural heritage; Actions to improve basic sanitation to reduce water pollution; New locks for passage of vessels projects; Discussion on financial resources destination, set priorities for each municipality and land titling;

In both presented scenarios of the Araguaia IEA, the Bananal Island and those in the Upper Araguaia and Lower Araguaia regions will be the most affected regions, and the Araguaia River Basin IEA states that power generation is feasible only for Santa Isabel (despite its cumulative effect with another plant, the Marabá dam, if both are implemented), Torixoréu and Couto Magalhães HPPs (in Upper Araguaia and Upper Mortes), highlighting that 90.4% of the main river length will be free of HPPs.

However, some HPPs had problems with environmental licensing due to the large flooded area and low power density (in Garças River). Thus, it is recommended that only small hydropower plants should be built in the Garças and Mortes Rivers.

[6] Mortes 2, Santa Isabel, Torixoréu, Couto Magalhães, Garças 3, Garças 6, Toricoejo and Água Limpa HPPs

Table 3
Analysis of the indicators of the PERH-TA, IEA Tocantins and IEA Araguaia River Basins' Scenarios.
Sources: Adapted from [3–41].

Scenario	PERH-TA	IEA Tocantins	IEA Araguaia
Trend (PERH–TA)/ Present Scenarios (IEAs)	– Existence of agricultural and urban-industrial activities, worsening the water pollution with new HPP; – Soil sensitivity in some regions and Transformations in aquatic environment in Tocantins and Araguaia rivers;	– HPP, totaling 12,929 MW and more 2 SHP, totaling 38.5 MW; – Loss of 6.573 km³ of territory in the basin, 6% of flooded riparian area; – 1542 km² of Cerrado area abolished, isolation of tributaries, and fragmentation of riparian ecosystems; – Increase in the municipal tax collection (financial compensation and ISS tax in Sono River, Mid-Tocantins, Sub-mid-Tocantins, Pará and Acará-Guamá regions); – Direct job creation in the region of the Sono River and Mid-Tocantins, indirect job creation in Upper Tocantins; – Greatest addition to the amount raised attributed to Mid-Tocantins.	– SHP, totaling 42.92 MW; – Sensitivity of the physical and terrestrial ecosystems in Upper Araguaia and Upper Mortes, with soil erosion in Mid Araguaia; – Sensitivity of the water in the municipalities, the sensitivity of aquatic environments (Upper Mortes and Lower Mortes); – Economic activity changes in Upper Araguaia; – Sensitivity of Socioeconomic issues in Upper Mortes and Lower Mortes; – Sensitivity of livelihood (Mid Araguaia and Lower Araguaia) and use conflicts between water uses for fishing, tourism and recreation in Bananal Island region, in Mid Araguaia.
Plan scenarios	– Generating of 7069 MW and only the HPP of the Sono River has not been constructed for its environmental and hydrological importance, "until its Water Plan has been approved".	– New 7 HPP, totaling more than 2710 MW; – 56% of the length of the river will be transformed into reservoir; – Loss of 182 km² of riparian forest in the Mid-Tocantins region, and of 12.15% with the deforesting process and the flooded vegetation; – Direct job creation in the Sono River and Mid-Tocantins regions.	
Alternative (PERH-TA)/ Future Scenarios (IEAs)	– Improvements in the soil sensitivity of Upper Araguaia. – High soil sensitivity in Upper Tocantins and Paranã region, – Very low potential for discharge regularization in Upper Tocantins, Lower Mortes and Sub-mid Tocantins; – High aquatic environment transformations in some regions like Acará-Guamá, Upper Araguaia, Mid-Araguaia, Sub-mid-Araguaia, Lower Mortes, Sono, and Itacaiúnas regions; – Novo Acordo dam, in Sono River, Água Limpa and Toricoejo dams in Mortes River, and Torixoréu dam, in Araguaia River, have not been installed, having generated 6585 MW	– Increase of 13 HPP totaling 1127 MW and 4 SHP totaling 44.8 MW; – Approximately 60% of the total length of the river will be transformed in reservoirs, – Loss of habitats and, consequently, of biodiversity, in 2 new rivers, flooding of an additional 3% of the basin; – Loss of 21% of the riparian vegetation affecting also the ecosystem and touristic potential of the river region; – Direct job creation with salarial benefits in almost all regions; —Expansion of the added value in the regions of Paranã, Upper Mid Tocantins, Sono, and Mid Tocantins.	– 9 new HPP totaling 2355.8 MW and 13 new SHP; – Impact on water quality and aquatic ecosystems (reduction of the aquatic biota diversity, interruption of migratory routes in the Upper Araguaia, habitat fragmentation on the Araguaia and Mortes rivers (Upper Araguaia and Upper Mortes); – Sediment regime changes in the Araguaia and Tocantins rivers confluence area due to Marabá dam construction. Conflicts with tourism, fishing, leisure activities, speleological and archeological heritage damage in Bico do Papagaio region (Sub-Mid Tocantins); – Cumulative effect of Marabá and Santa Isabel HPPs can have problems with the environmental licensing process (due to the monitoring of aquatic ecosystems and aquatic mammals); – Sensitivity of water resources on Bananal Island and possible conflicts of irrigation water uses; – Sensitivity of environment due to remnants native vegetation and conservation units in Upper-Mid Araguaia; – Socioeconomic conflicts with indigenous lands and human settlements; Interference in communication and circulation flows between communities, loss in the standard of human settlement and loss of agricultural land (Upper Araguaia).

Furthermore, the environmental licensing process pointed out that at least 3 projects have had some environmental problems [88–91][7].

[7] Such as (1) the Santa Isabel HPP, which affects 3 protected areas and 131 natural caves in the region, and possible interference in indigenous lands [88,89]; (2). Serra Quebrada HPP, whose environmental and technical feasibility studies are suspended in compliance with a recommendation of the Public Prosecutor's Office in the state of Tocantins [90] and (3) the Couto Magalhães HPP, which had the termination of its concession contract requested by the National Electric Energy Agency [91].

The IEA Araguaia recommendations state that further viability studies are necessary for the selected alternative, specially to address the indigenous issue (Mortes 2, Santa Isabel, Torixoréu, Couto Magalhães, Garças 3, Garças 6, Toricoejo and Água Limpa HPPs); and that sediment measurement stations must be implemented in the river basin due to the large sediment input [44].

Then, the impacts on sensitivity maps of the river basin were shown in Araguaia IEA, but the assessment could have provided a

more effective analysis of the impacts consequences and their cumulative and synergistic effects.

The three studies recommended the implementation of fish transposition systems or other effective measures for migratory fish; Both the PERH-TA and the IEAs recommended management actions and environmental conservation of Cerrado biome, covering erosion control (especially in Upper Araguaia), and the Integrated environmental Program such as icthyofauna macro studies, mapping of migration routes, among others.

Also, they strongly recommended the increase and improvement of institutional linkages to promote a territorial management system, and consolidate the permanent management structures in the Araguaia River Basin and the regional institutional strengthening. The Tocantins IEA states that the power sector should be included in the institutional management processes of the river basin, because it does not always happen.

5. General analysis and discussions

Therefore, it is possible to conclude that the environmental assessments studies analyzed contributed to give an idea about the HPP's general impacts and its main constraints on the River Basins.

These studies make several recommendations for the power sector, as well as for the municipal, state and federal governments. Both PERH-TA and IEAs state that there is an institutional lack in the region and that there is a need to implement a management system for the river basins. Therefore, to start this process, in a short term, a mechanism for intersectional linkages within the government should be created via decree.

The implementation of an adequate river basin policy structure depends on political will, consensus among parties, and availability of resources as well as technical capacity. Without closer institutional communication for river basin management, it is hard to coordinate the multiple water use interests [41].

As for the Araguaia River, several SEA studies in the major rivers around the world suggest the possibility to maintain for rivers free of dams, also pointing out at the benefits of energy generation and regulation of the river to prevent flooding [11]. Thus, development scenarios covering multiple dams in the same basin should choose those HPPs that have less social and environmental impact [92].

The IEA of the Tocantins River Basin highlighted that species studies are generally conducted at the same time as the Environmental Impact Assessments (EIA), and that the lack of information does not permit a further ex-ante analysis on this.

Some authors have stated that the tools must be impartial and must be implemented in an ex-ante analysis, previous to the decision-making process, so that its conclusions are valid and not the object of skepticism or resistance by interested parties, which is a common situation today in Brazil [93]. Regarding this issue, the SEA should not be a mere political instrument disconnected from the effective planning process [4].

In spite of the fact that the three studies have stated that the fish transposition has to be implemented in the dams, it is important to know that the effectiveness of the technologies for passing fish systems at large Dams are not yet verified (*e.g.*, fish ladders or elevators) [94]. There is no monitoring and few studies about its real contribution for fish passes, “most facilities have been considered ineffective for conservation purposes” since the existing technologies doesn't permit the circulation of a high number of fishes and there is a downstream fishes' accumulation trying to migrate upstream [95].

Regarding social issues, although the construction of HPPs creates a significant number of jobs (though most are temporary), further investments are needed in other economic activities, such as sanitation (Upper and Mid Tocantins River) [41], tourism and sustainable fishing. Furthermore, indigenous culture preservation, respect for riparian lands and natural and cultural heritage enhancement, rescue archeology, environmental education promotion and creation of new conservation areas, are needed[8].

Therefore, the Environmental Assessment tools are not without criticism [9]. As the IEAs are linked to the hydropower sector, they are restricted to the reservoir impacts and their possible cumulative and synergistic effects. On the contrary, the SEA, which does not only cover the power sector, is able to be more comprehensive, delivering clearer and more impartial results.

Gonçalves et al. [9], as well as Pires [96], have stated that, despite IEA's contributions to a more integrated design of the dam on a river basin, the SEA could be more effective than the IEA from the point of view of making the energy planning sustainable, since the IEA is an operating instrument and not a strategic one.

IEA identifies, *e.g.*, the largest areas of fragilities in the river basin, but “does not impede, *a priori*, the implementation of these projects” [97]. These tools do not decide, they just seek to provide help in the decision making process [98].

According to the authors, several adjustments are needed to improve the IEA process. For example, the environmental studies at the time of the Hydroelectric Inventory Study (using IEA methodology) should be analyzed by the environmental or regulatory agency [25], and has to involve public participation in the decision-making process, instead of going directly to the National Electric Energy Agency–ANEEL for review and approval [99].

Most of IEA are criticized for not analyzing policies, plans and programs, limiting itself to describing them. Then, there are “no discussion and evaluation of truly strategic issues” and frequently “scenario analysis is focused on discussing how to meet the growing demand for energy in Brazil” [4].

Since IEA is often considered similar to Environmental Impact Study (EIA) in some aspects, the Brazilian Public Prosecutor's Office considers that there is a lack of depth or originality in many of these studies and states that they are losing their strategic importance and that “IE assessments contribute little or nothing to decisions regarding the use of water resources”. However, EPE, who is responsible for implementing IEA in the hydropower sector justifies its use by arguing that it is a new instrument that needs adjustments [100][9].

6. Conclusion and final remarks

Analyzing the cases of the Tocantins and Araguaia River Basins allows, to identify that the assessment tools are not a greatly contributing to the hydropower sector decision-aking process. The power sector continues to pursue its hydroelectric works, despite the environmental or social fragilities of some areas, as identified by the studies. In fact, some HPPs that were considered feasible for the river basin in the analyzed studies (*e.g.* Santa Isabel and Couto Magalhães HPPs) did not receive environmental licensing. Often, the planned dams are already decided by the power sector to be implemented, without considering the study's results.

Therefore, it would be more effective if the analysis of the IEA and SEA were taken into account in a timely manner, before the environmental licensing process, in order to avoid wasting time and resources. Also, environmental agencies should assess

[8] These actions are included in the Basic Environmental Plan (PBA) for the obtaining the HPP Installation License.

[9] Citing the Federal Government.

the IEA and give their opinion on these studies, so that the Environmental Impact Assessment (EIA) can really collaborate with the environmental licensing process, making a more useful contribution to the decision-making process for the various stakeholders in the river basin. Otherwise, these studies do not meet their real objective.

Also, it would be important to create a method for monitoring the implementation of the strategic and integrated assessment recommendations at the national and state levels (*e.g.*, at the national water agency level). Being a relatively new tool in Brazil, IEA can be improved by the experience gained in its application integrating the electricity sector, the National Water Agency, River Basin Committees and environmental licensing agencies, as happens with PERH studies.

The Hydropower Inventory should apply the IEA to every identified hydropower potential in the river basin, verifying every possibility in order to choose the best one. According to EPE[10], there is no way to apply the IEA for all hydropower potential in large areas (as the Amazon Hydrographic Region). It demands more infrastructure, adequate time and resources for implementation of the studies.

Therefore, more substantial environmental studies on the Amazon and Cerrado biomes (*e.g.*, diversity of vegetation and fish populations) should be carried out; environmental, social and cultural programs (rescue archeology, protection of indigenous cultures, *etc.*), should be developed and control and management measures, beyond EIA regulations, should be implemented by the government and other private institutions.

Hydropower is a good alternative energy for Brazil, providing clean power production and relative low costs (compared to fossil fuels). However, its social and environmental impacts should be reduced, avoiding HPPs in preservation areas and prioritizing alternatives' complementarity between renewable sources (*e.g.* wind x hydropower in some river basins during the dry season), considering the implementation of new technologies, or alternatives between river basins, in order to contribute to a real sustainable development planning.

Due to the importance of the River Basin Management, mainly in developing countries that have weak environmental planning systems, this paper can contribute to discuss some relevant issues to verify how these tools can be more effective.

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